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7.5: Progress on Fabrication and Testing of the Omniguide Traveling-Wave Tube Structures

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Abstract: *We have designed, fabricated and tested with low power a novel W-band traveling-wave tube (TWT) structure based on a slow-wave cylindrically-symmetric photonic band gap (PBG) structure, or an "omniguide". PBG TWT structures have great potential for very large bandwidth and linear dispersion. The omniguide structure was designed and fabricated with silica dielectric with a copper harness. Cold-test results were found to be in excellent agreement with the design. A band-width of more than 10 per cent was demonstrated. This structure is designed to generate millimeter-wave rf when driven by a 2-A, 120-kV electron beam.*

Keywords: dielectric-loaded waveguides, millimeter-wave power amplifiers, photonic band gap structures, traveling-wave tubes (TWTs).

Introduction

Compact, efficient, high-bandwidth and high-power mm-wave sources are essential for many applications in secure communications, environmental monitoring, imaging, spectroscopy for remote sensing in nonproliferation, and basic research such as radio astronomy [1,2]. Spectroscopy missions in particular become more important at frequencies above 100 GHz, up to the THz range, and with bandwidths up to 30%. Until now, microwave vacuum tube technology has not scaled favorably to short wavelengths and wide bandwidths.

Commercial microwave tube amplifiers are available at frequencies up to only 100 GHz (W-band) and have to trade off maximum output power against bandwidth. A wide-band mm-wave traveling-wave tube (TWT) amplifier development is underway at Los Alamos National Laboratory. We have constructed a 95 GHz TWT using a vane-loaded waveguide as a slow-wave structure and demonstrated a 7% bandwidth in a cold test [3]. Although promising, this approach leads to significant engineering and fabrication challenges. As a result, we proposed to use the photonic band gap (PBG) structures [4] for constructing a TWT at 100 GHz, a completely novel approach. PBG structures are periodic structures of dielectric material. An omniguide [5] is a one-dimensional version of the PBG structure representing a periodic system of concentric dielectric tubes (Figure 1(a)). By modifying the dimensions of the omniguide, namely, the diameter and thickness of dielectric tubes, one can engineer a structure that would resonate at the frequency of interest (95 GHz) and confine the mode at the center with the field pattern resembling the one of the TM01-mode of the cylindrical waveguide (Figure 1(b)), and with the phase velocity along the omniguide less than the speed of light. This mode is a good candidate for the operating mode of a traveling-wave structure.

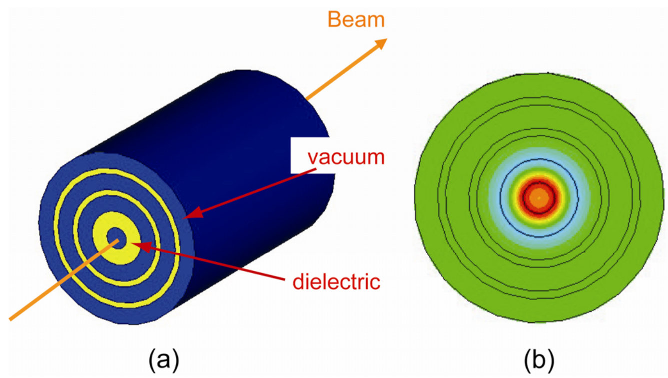

Figure 1. The schematic of an omniguide, the yellow area is dielectric and blue area is vacuum (a); the longitudinal electric field magnitude in the TM_{01}-like mode of an omniguide computed with CST Microwave Studio (b) [6].

The omniguide confining the TM01-like mode will have several advantages over a metallic vane-loaded structure. First, it has lower losses at W-band than copper structures. Second, by using dielectric materials, one can, in principle, achieve more than one hundred percent bandwidth. Third, TWTs based on dielectric structures will have a linear dispersion relation, which affords great beam-to-wave interaction, permitting beam interaction with many frequencies at once. Fourth, since the modes cannot be confined at frequencies outside of the band gap, the omniguide TWT has a reduced higher-order-mode content. Finally, fabrication of dielectric designs has the potential to be much cheaper, easier, and faster, enhancing the commercial transferability of the technology.

Design, Fabrication, and Tests of the Omniguide TWT Structure

In this conference's presentation, we will report the design, fabrication, and testing of the first W-band omniguide traveling-wave tube structure. We employed silica which has dielectric permittivity of 3.8 for construction of the omniguide. This material slows the mode to half of the speed of light, which matches the speed of the 120-keV electron beam. The dimensions of the structure are summarized in Table 1.

We have conducted end-to-end modeling with CST Microwave Studio [6] and designed a quasi-optical coupler for transferring mm-wave power from two WR10 waveguides into the omniguide structure. According to our design, the power couples through such a system with more than 10 per cent band width.

Table 1. Dimensions of a 100 GHz Omniguide TWT structure

Radial period, a	0.92 mm
Thickness of the dielectric layer, d	0.46 mm = 0.5*a
Inner layer ID	0.92 mm = a
Inner layer OD	4.6 mm = 5*a
Structure length	25.4 mm

Silica tubes for the omniguide structure were manufactured by the Silica Glass Products, Inc. in Willow Grove, the central tube was tapered slowly to allow for quasioptical coupling of the microwaves from two WR10 waveguides into the omniguide structure. A symmetrical coupler on the downstream side of the tube serves for the power output. The metallic hardware was made of high-conductivity copper and the copper parts were brazed together to maintain high conductivity and good vacuum in future high-power tests. The outside shape of metallic hardware in the structure was designed to fit the electron beam test stand for high power tests. The omniguide TWT structure assembly is shown in Fig. 2.

Figure 2. A photograph of the assembled omniguide TWT structure.

The omniguide TWT structure was tested in our mm-wave laboratory with the HP8510C network analyzer and Oleson Microwave mm-wave heads. The structure transmitted microwaves from 90 to 100 GHz, the measured transmission for the copper-harnessed structure is shown with the black line in Fig. 3. The measured losses of about 10 dB were mostly due to the connection hardware and not the omniguide structure itself. In Figure 3 the transmission through the LANL's vane-loaded TWT structure [3] is shown for comparison, with a grey line. It can be easily seen from the figure that the vane-loaded structure has much smaller bandwidth (around 7 per cent) and higher losses (more than 20 dB). Therefore one can expect a better performance from the omniguide structure with respect to mm-wave power generation.

Conclusion and Plans

Our nearest future plans include performing a gain experiment with the omniguide TWT. The structure will be installed inside of a solenoid in our mm-wave electron beam test stand [3], which employs a 20-A, 120-kV electron beam. The structure will be driven from 90 to 100 GHz, and the gain (at low power) will be measured with available diagnostics to verify the interaction concept. Next, we will conduct a moderate power and moderate bandwidth experiment. We plan to demonstrate generation of 100 W of mm-waves with 10 per cent bandwidth.

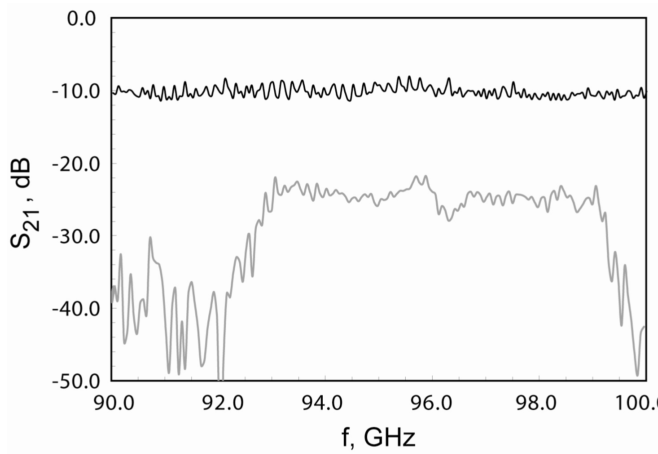

Figure 3. Measured transmission through the omniguide TWT structure which is shown in Figure 2 (black line). For comparison the measured transmission through the LANL's W-band vane-loaded TWT structure [3] is shown (grey line).

In conclusion, important steps have been taken for designing a TWT with a PBG slow-wave structure. A simple, cylindrically symmetric design, called an omniguide, was completed, fabricated, and cold tested. The cold tests confirm the low insertion loss and the extremely wide bandwidth of this type of device. An omniguide structure was manufactured and fully prepared for the first real hot test with an electron beam to demonstrate mm-wave power generation. We believe that the current design of the structure can be improved even further to achieve peak output power of more than 1 kW and bandwidths of more than 20 per cent.

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